UNCLASSIFIED

AD NUMBER
AD215628
NEW LIMITATION CHANGE
TO Approved for public release, distribution unlimited
FROM Distribution: Further dissemination only as directed by Chief of Naval Research, Arlington, VA, 15 Feb 1959. or higher DoD authority.
AUTHORITY
ONR ltr, 27 Dec 1971

THIS PAGE IS UNCLASSIFIED

UNCLASSIFIED

AD 215628-L

Armed Services Technical Information Agency

ARLINGTON HALL STATION
ARLINGTON 12 VIRGINIA

FOR
MICRO-CARD
CONTROL ONLY

1 OF 1

UNCLASSIFIED

Columbia University
in the City of New York

HUDSON LABORATORIES
DOBBS FERRY, N.Y.

Technical Report

No. 70

Hydrophone Development At Hudson Laboratories 1951 to 1958

by

Edward T. O'Neill

FEBRUARY 15, 1959

Contract

N6-ONR-27135

ASTIA No. 215628

CU-90-59-ONR-271-Phys.

Columbia University
Hudson Laboratories
Dobbs Ferry, N. Y.

R. A. Frosch
Director

Technical Report No. 70

HYDROPHONE DEVELOPMENT AT HUDSON LABORATORIES 1951 to 1958

by

Edward T. O'Neill
Mechanical Engineering Department

February 15, 1959

This report consists of 30 pages

Copy No. 44 of 75 copies

Research sponsored by
Office of Naval Research
Contract N6-ONR-27135

TABLE OF CONTENTS

[redacted]

INTRODUCTION

This report is intended as a presentation of our experimental developments in the hydrophone field. The standardized and special types of hydrophone construction will be shown together with sources of basic material. Equipment development in this field will be reviewed and recommended suggestions for further development efforts will be suggested.

BACKGROUND

In the early days of Hudson Laboratories underwater research activity, the widely used acoustic detectors were expensive commercial barium titanate devices having limitations under high hydrostatic pressures. In the Mechanical Engineering Section, experiments were conducted to ascertain the practicality of making our own hydrophones better suited to deep water use. The first problem was that of finding a suitable backing material which would not diminish the sensitivity of the barium titanate cylinders used. An experimental program showed that the density of the backing material, particularly in the low frequency range of listening, had no perceptible difference on the sensitivity of the assembly. A hydrophone unit was made which met our deep sea needs and has been our standard type detector since. Details of this unit will be explained below.

As need arose, other problems were encountered in the assembly techniques of these and other types of listening and transducer units. More recently, improved equipment requirements have pointed up the need for better hydrophones from the standpoint of better sensitivity and higher capacity, and this has given rise to a more critical approach in the choice of materials and in assembly methods. Recent efforts have been made to meet these demands by the use of better ceramic materials (zirconates), and by the improvement of packaging techniques(shielding).

BASIC ACOUST C TOOLS

1. THE STANDARD THREE-ELEMENT HYDROPHONE - The most basic listening tool of the laboratory, shown in Fig. 1, will be considered in detail. This is a series-wired three-cell unit with a capacity of .006 microfarad, and a sensitivity of about -92 db per dyne cm^{2} --reference 1 volt.*

A - Crystal Requirements. The barium titanate crystals used in the standard three-element hydrophone were selected with the following specifications:

Physical

Cylindrical 1¼-in outside diameter
Length 1¼ in
Wall thickness approximately 1/8 in
Electrode surface applied to within 1/8 in of inside and outside edges of cylinder

Electrical

Capacity of at least .018 microfarads
Lower Curie point below 0°C
Uniform direction of polarization
Dielectric constant (at 25°C)

B - Boot. The envelopes for the series-connected plastic-fillen crystals were bottomed cylinders made of rho-C neoprene compound, having acoustic transmission properties closely approximating those of water.

C - Wire Connections. The series connections were made with an insulated tensolite wire while the takeout wires were made of Signal Corps wire (WDITT), selected for the durability of its insulation in the compressive type of rubber seal gland adopted successfully

---

* All db measurements henceforth in this report will have this same reference.

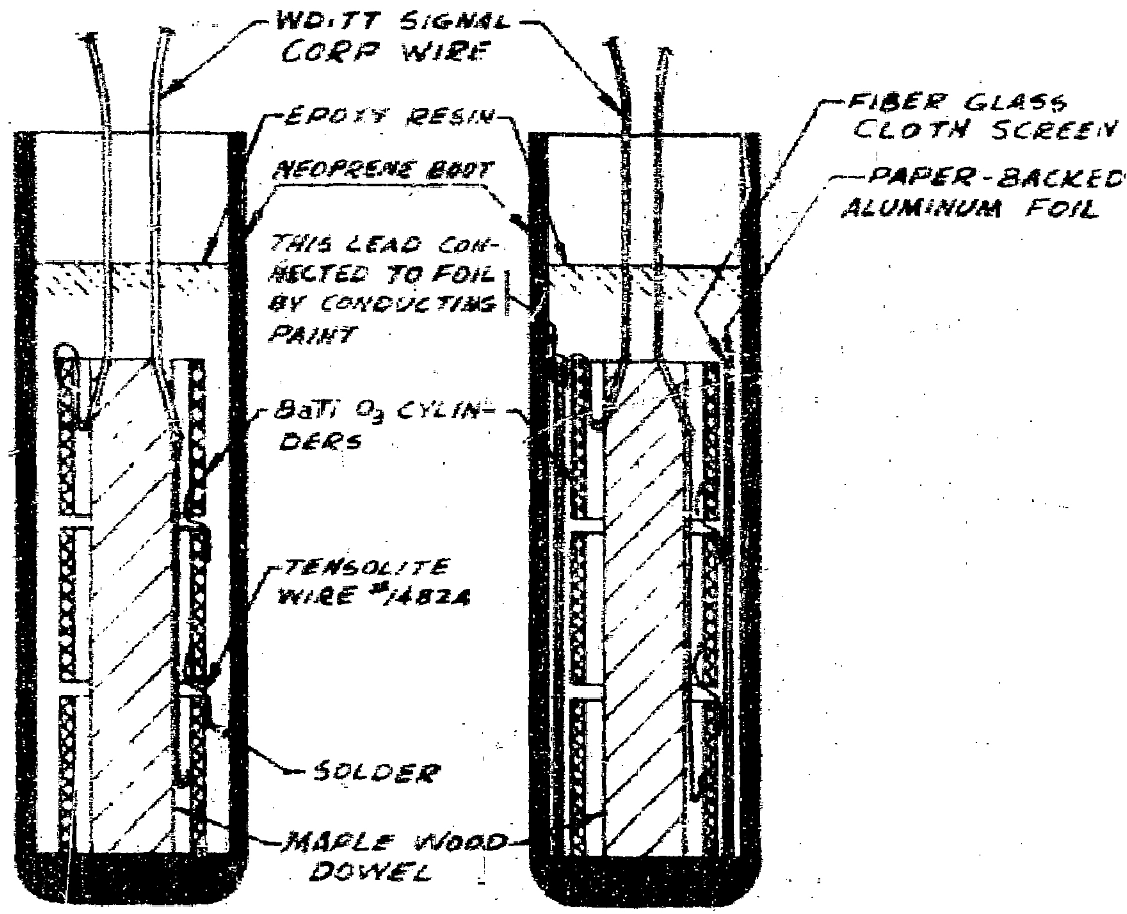


Fig. 1 STANDARD THREE-ELEMENT HYDROPHONE

Fig. 2. SHIELDED THREE-ELEMENT HYDROPHONE

for widespread high pressure use in laboratory devices. Low temperature solder was used with a minimum of heat (temperatures above high curie point of 130°C will destroy polarization).

D - Plastic Material. Experiments indicated that a completely plastic-filled backing for the three-element assembly was wholly satisfactory. A room curing epoxy resin plastic was found. However, the excessive exotherm approached the high transition point of the barium titanate material and threatened the polarization of the crystal. A maple wood dowel was employed as an assembly aid as well as a filler, and this lowered the unit volume of the curing plastic and consequently the exotherm. The epoxy resin used had the disadvantage of high viscosity presenting the problem of entrapment of air in the capsulated unit. A suitable "thinner" material was found which made the plastic more fluid at no appreciable mechanical or electronic sacrifice. The plastic finally adopted was made up of Aries #304 Epoxy Resin, Aries #101 Hardener, and a thinner material.

E - Hydrophone Assembly Procedure. The three crystals were first wired in series, and a wooden dowel previously drilled and provided with Signal Corps wire leads, was inserted into the stacked cylinders. After the remaining connections of the Signal Corps wires to the crystals were made, the whole assembly was lowered into the boot. The capacity was checked, and the plastic was prepared for pouring. To a base weight of Aries #304 Epoxy Resin, 10 per cent #101 Hardener (diphenylamine) and 8 per cent thinner (styrene oxide) were added. The materials were stirred at a slow rate to prevent entrainment of air. About five minutes of mixing time for the plastic was sufficient before it was poured into the assembled unit. Manual manipulation of the boot was necessary to eliminate air bubbles, a possible cause of acoustic losses and mechanical weaknesses. The completely plasticized unit was allowed to "cure" for about twelve hours before calibration.

F - Fastening of Completed Unit to Equipment. The extended section of the boot on the completely plasticized unit was applied over a corrugated metal projection on the equipment, and an aeroseal hose clamp was used to secure it. The void between the metal and the plastic was completely filled with castor oil, thus affording a relatively incompressible backing necessary in high pressure use.

G - Material Sources.

Barium titanate crystals were available from several sources. (See later section on supply problems.) Final selection was made only after actual assembly and evaluation of samples.

Wire - The interconnecting wire for the crystals was Tensolite #1402A, made by Tensolite Wire and Cable Company, Tarrytown, New York. The more durable leads were of Signal Corps wire WDITT made for the Signal Corps by many wire concerns.

Boot - The boot was manufactured by B. F. Goodrich Industrial Products Company. An original pattern was made and retained by the company. Boots were molded on order from black neoprene stock #35003, a material with greater resistance to damage by sunlight or oil than rubber, and with the desirable acoustic properties of pure rho-C rubber.

Plastic - The epoxy plastic used was Aries #304, the hardener Aries # 101, and the thinner styrene oxide. All of the above were procured from Aries Laboratories, 270 Park Avenue, New York City. Many other industrial sources of comparable products are also available.

II. SHIELDED THREE-ELEMENT HYDROPHONES

A - <u>General Comments.</u> The Electronics Department studied the effects of shielding the standard three-element hydrophone to diminish electrostatic pickup. Their findings indicated that the shielded hydrophone finally developed (see the diagram in Fig. 2) permitted a 35 db improvement at a sacrifice of 1 db in sensitivity.* The capacity of the completed unit was about .006 microfarads, and sensitivity about -93 db.

B - <u>Shield Materials</u>. Copper screen wire, aluminum foil, aluminum foil insulation paper, perforated foil insulation paper, and a boot lining of conductive silver paint were tested. Best results were obtained with a single-sided foil paper.

C - <u>Insulation Materials</u>. As the electrode surfaces of the barium titanate crystals were exposed to the shielding material, an insulator was necessary. A material sufficient for the proper shield spacing and at the same time not solid enough to resist permeation by the plastic was finally found. Fish paper, fiber, milar, and fiberglass screen (#8 mesh) were tested, the last with the most favorable results.

D - <u>Assembly Procedure</u>. The procedure outlined for the standard three-element hydrophone was followed up to the point where the assembled and wired crystals were ready to be inserted into the boot. The crystal assembly was "rolled" into a 4"×5" piece of fiberglass screen which was fastened with scotch #33 tape. The shield paper (single foil) size $5\frac{1}{2}$"×$5\frac{1}{2}$" was applied tightly to the screen insulator with the foil side out. The bottom was also shielded by folding the lower extended side foil under the unit. Connection of the shield (aluminum) to the outer electrode surface of the top crystal was made by an uninsulated wire which was secured with a "glob" of conductive silver paint. After the shield was secured with strips of scotch #33 tape, it was lowered into the boot and "potted".

---

* Developmental work on shielded hydrophones was conducted at Hudson Laboratories by Thomas Pappas.

E - Material Sources.

Fiberglass Cloth Screen, #8 Mesh was procured from Plastic Woven Products Co., 51 Camden Street, Paterson, New Jersey.

Shield Material, an aluminum reflective insulation "Foiltex", was manufactured by Hersey Paper Lining Company, Melrose, Mass.

Conductive Silver Paint # 4756 was obtained from E. I. Dupont de Nemours, Electro Chemical Department, Wilmington, Delaware.

III. THREE-INCH DIAMETER HYDROPHONES

General Comments. This type of unit is made of barium titanate cylinders of the following dimensions, 3-in outside diameter, 6-in length, and thicknesses of 3/32 in and $\frac{1}{4}$ in . The most significant mechanical feature of this type of assembly was the use of an epoxy plastic to glue the end plates to the crystals. Without additional backing, the 3/32-in walled cylinder withstood pressures up to 4950 psi, at which point the cylinder collapsed. It is not known to what maximum pressure the unit is useful. The crystal, with cemented end plates, was fitted with a rubber boot which in turn was made secure with stainless steel aero-seal hose clamps (see Fig. 3).

IV. MULTI-CELL-- HIGH CAPACITY HYDROPHONES

A - Preliminary Comment. This unit was designed for a particular situation in which no preamp was to be used, where a high capacity was needed to reduce line impedance. The configuration of crystals and the series-parallel wiring arrangement was designed to meet the needs of the electronic system employed (see Fig. 4).

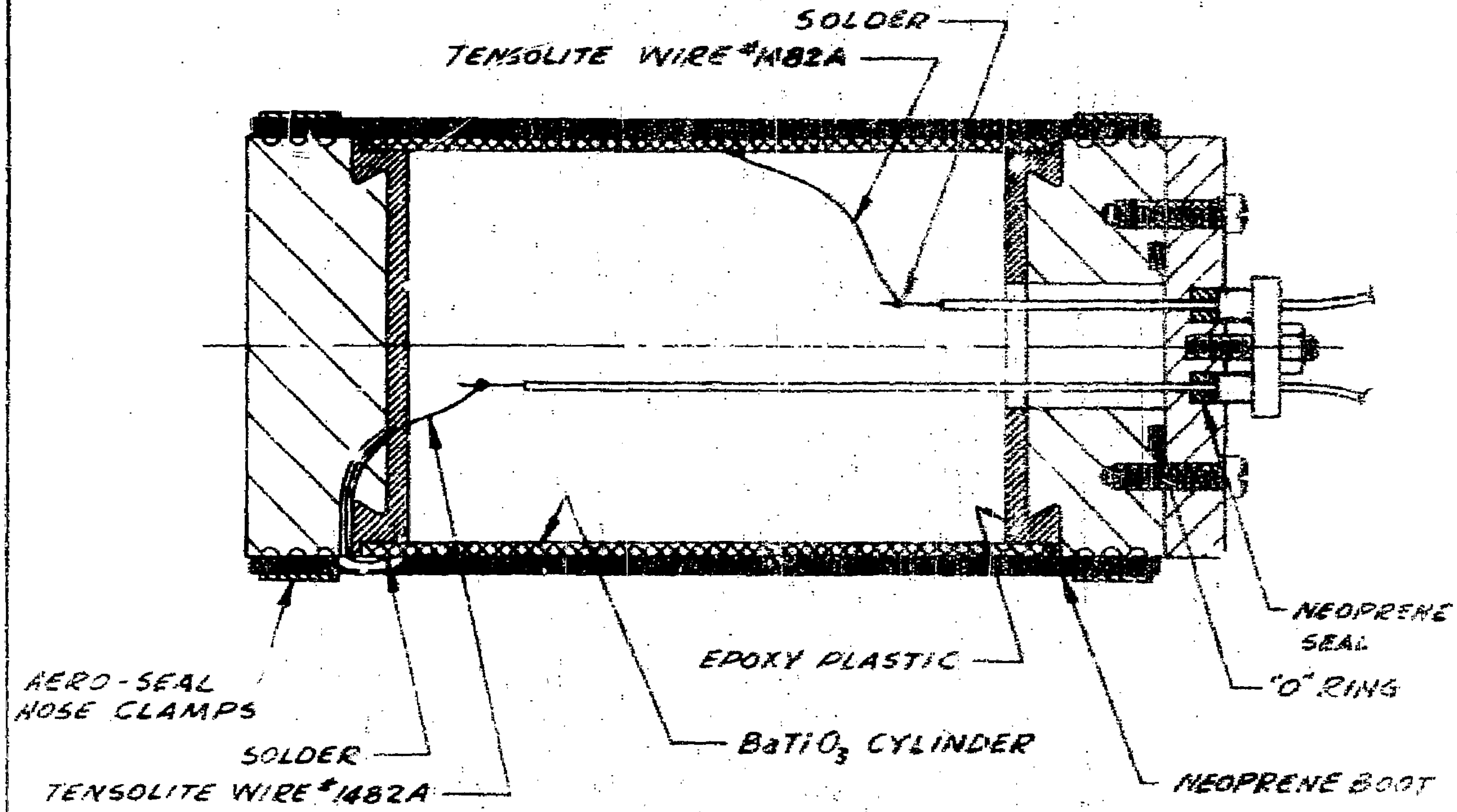


Fig. 3. THREE-INCH DIAMETER HYDROPHONE

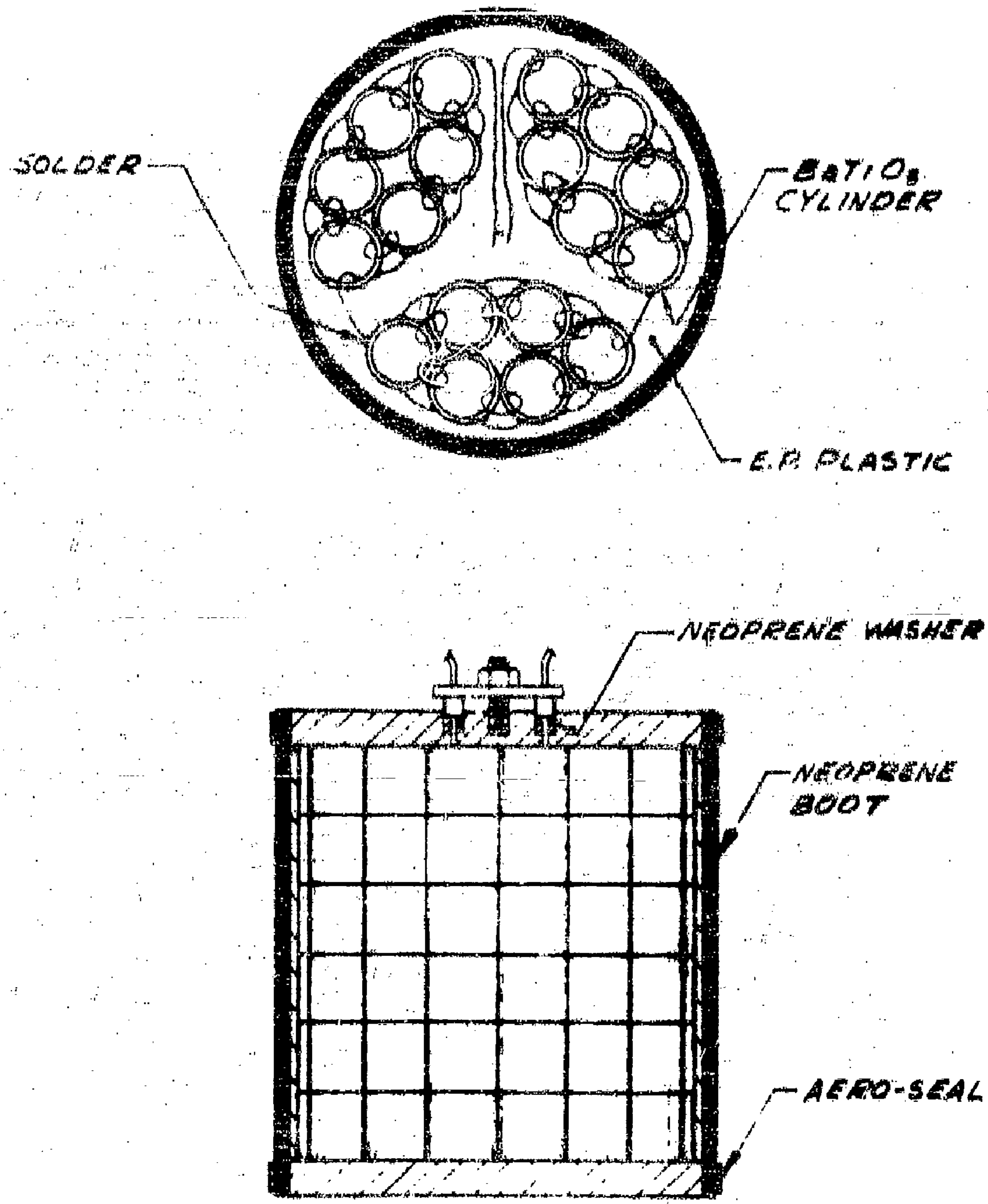


Fig. 4. ASSEMBLY PATTERN OF MULTICELL HYDROPHONE

B - General Description. This receiver consisted of one hundred and eight $1\frac{1}{2}$-in × $1\frac{1}{2}$-in cylinders assembled in stacks between two stainless steel plates of 9-in diameter. Three subassemblies were made up of thirty-six crystals arranged in stacks six crystals high. Crystals within each stack were parallel wired, while the three clusters of thirty-six crystals were series wired, forming the completed unit. This resulted in a receiver with a capacity of .18 microfarad and a sensitivity of -93 db.

C - Assembly Procedure. In the preliminary assembly operation, nine-inch rods were formed by gluing six crystals together with E. P. plastic (to be discussed below). Six such rods were bundled together and all thirty-six crystals were parallel wired. Three such major assemblies were arranged somewhat in the form of a hexagon on the stainless steel base plate. They were then series wound with the terminal leads brought out through compression seals in the upper stainless steel plate. A metal mold sprayed with mold release was securely bolted around this entire assembly, and it was then plasticized. Care was observed to fill all voids completely. After the plastic was thoroughly cured (this took approximately one day), the mold was removed and a rubber sleeve, made secure with stainless steel hose clamps, was then applied.

D - Problems Involved.

Configuration. Considerable experimental effort was spent in ascertaining that the crystals, located well within the outer periphery of the unit, contributed their equal share to the overall sensitivity of the assembly. Prototype test units were made with individual cell connections. Calibrations were then made, and it was found that a crystal surrounded by six outer cells matched them in individual sensitivity.

Plastic Problems. A difficulty in plasticizing a large unit of this kind was pouring a large volume of plastic without generating an exotherm of deleterious effect on the polarization of the crystal components. Exhaustive experimentation with many types of plastics curing at room temperature resulted in the selection of a filled modified epoxy plastic which met our requirements. This is a three-component plastic manufactured by the Electronic Plastic Corp., 675 Barby Street, Brooklyn, New York. The final formulation was 2 per cent Hardener #5 and 2 per cent Activator #2 added to Base Resin #2334-1.

V. ULTRASONIC PROBE HYDROPHONES

A - General Comment. This type of listening device is made of a barium titanate cylinder 1/16" diameter by 1/16" length. It has particular application to high frequency acoustic study. Because of its minute size, difficulties were encountered in arriving at a satisfactory assembly technique.

B - Types of Units. Two methods of mounting were developed with success, one a rigid mount and the other a flexible wire mount.

Rigid Mounted Ultrasonic Probe. This was the type of unit that was used where a more precise location of the probe was essential (See Fig. 5). The unit was mounted at the end of a brass capillary tubing. Wire connections to the small crystal were accomplished through the use of silver conducting paint. For insulation, a thinned neoprene coating was applied repeatedly until an infinite resistance reading between the electrical terminals and the water into which the unit had been submerged was attained. This type of probe had a capacity of 300 micro-microfarads with a sensitivity of -140 db.

Flexible Wire Mounted Unit. This unit was one that was made by mounting the 1/16-in crystal on an insulated wire which had the wire strands spread out and rolled back inside the crystal (see Fig. 6). The wire was secured electrically and mechanically to the internal electrode of the crystal by means of silver conducting paint. Neoprene was applied to cap off the unit and secure the unit to the wire insulation. The insulation of the second wire was secured to the first; a single wire strand was brought to within 1/8 in of the crystal where an electrical contact was made between it and the outside electrode by means of silver conducting paint. The tested unit was then insulated with a neoprene coating.

C - Material Supply.

Neoprene #700 and Neoprene Thinner N-450-1 obtained from Gates Engineering Co., 100 S. West Street, Wilmington, Delaware.

Probe crystals were secured from Clevite Electric Components, Cleveland, Ohio.

Silver conducting paint E. I. Dupont #4756 was used.

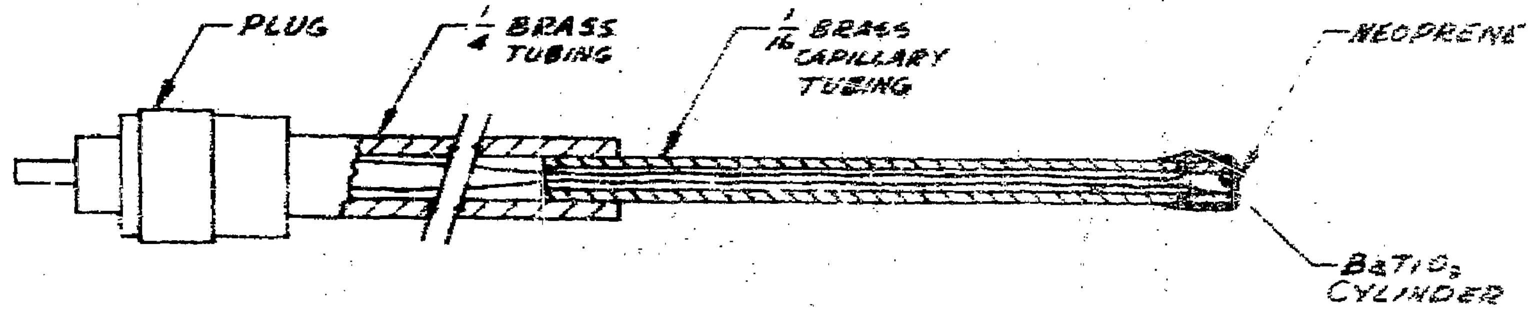


Fig. 5. ULTRASONIC PROBE (RIGID MOUNTED)

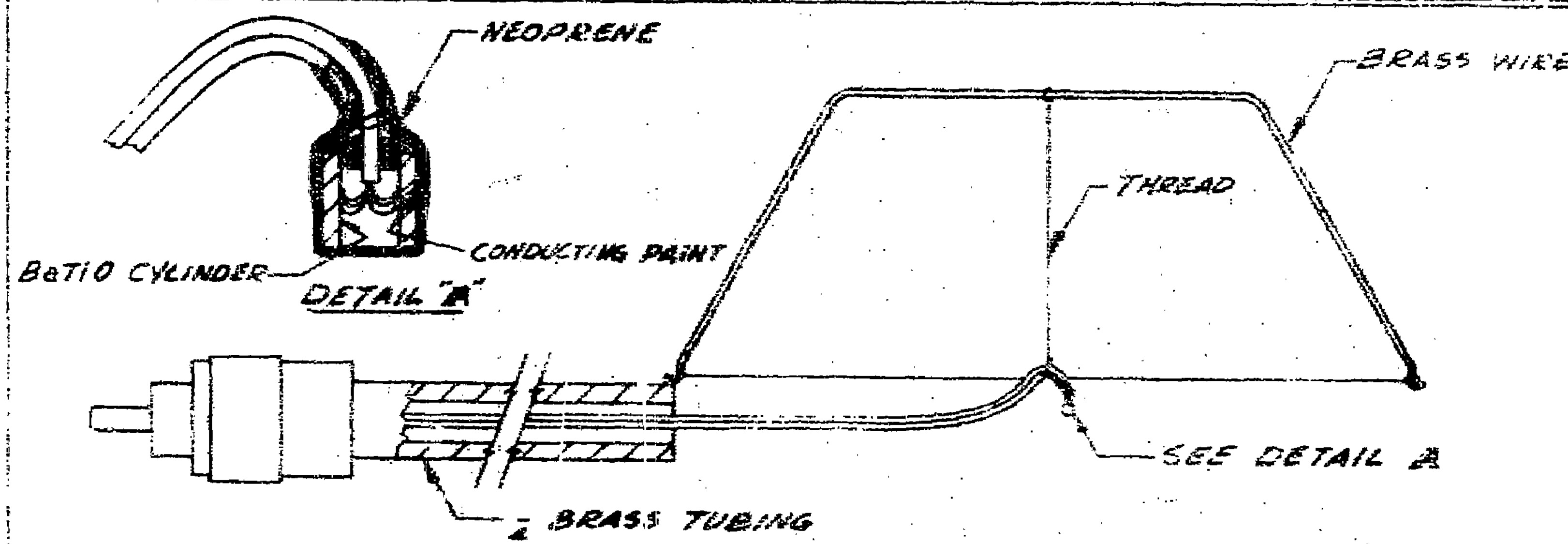


Fig. 6. ULTRASONIC PROBE (FLEXIBLE-WIRE MOUNTED)

CRYSTAL SUPPLY PROBLEMS

In an effort to meet laboratory requirements for hydrophones having at least the sensitivity of our standard calibration units (-91.5 db), a set of basic requirements for dimensions and electrical properties was sent to all known commercial companies dealing in piezoelectric materials. Certain requirements could be varied, but the lower curie point could not be above 0°C, and in the attainment of this in barium titanate material a certain part of the sensitivity was necessarily sacrificed. Some manufacturers offered a thinner walled crystal in an attempt to attain greater capacity and sensitivity, but the final evaluation was not very encouraging. It was evident that those better known suppliers, making standard units under Navy Specifications, did not and apparently could not meet Hudson Laboratories requirements without major modification of routine ceramic mixes or crystal dimensions. In practically all cases they showed great reluctance to any variation of "Navy Specs", which were obviously low. Some of the companies that did supply test samples from the shelf had an inferior product. Others made some modification, but again the results of the finished crystal were not satisfactory. At the present time, none of the companies is able to supply wholly satisfactory crystals. It is very probable that our standard units are made from an unmodified barium titanate material and, therefore, exhibit a higher sensitivity than the samples. The best we have been able to procure for evaluation were samples -103 db equivalent to about -93 db in a completed three element unit. This is below our proposed requirements by 1.5 db.

<u>Method of Evaluation</u>. A sample crystal, received for appraisal from one of the various companies, was made into a single cell hydrophone in the same fashion as our standard "three element" unit. It was referred for calibration, and its sensitivity was compared with that of competitive crystals. Our calibration (atmospheric) device uses

a comparative means of evaluation where the prime standards are "Orlando Calibrated Units". The range of frequencies normally tested is from 2 to 100 cycles per second.

<u>Suppliers</u>. A list of many of the companies contacted may be found in the Appendix.

<u>Observations</u>. Of all the samples tested, it was found that none satisfactorily met laboratory demands. One of the crystals (U. S. Sonics) indicated an acceptable sensitivity, but at a sacrifice of capacity of .0055 mfd. It is evident that the barium titanate available now, modified for a depressed curie point, is incapable of producing an acceptable unit (-92 db).

<u>Possible Solution</u>. Samples of lead zirconate material were made into a three-element hydrophone with a capacity of .00516 microfarads and a sensitivity of -94 db. These lead zirconate hydrophones cost about five times as much as barium titanate hydrophones. It has been suggested that by means of a judicious selection of crystal size, two zirconate elements could be used instead of three; the resultant sensitivity would be higher than that of the standard barium titanate hydrophone by 2 to 3 db. A further modification of this two-element hydrophone, reversing the polarization of one of the two crystals, would obviate the need for shielding, thereby saving 1 db normally sacrificed in a shielded unit. A two-element zirconate hydrophone of acceptable sensitivity offers, as an additional advantage, a capacity higher than that of the standard hydrophone. The possibilities in the design of such a hydrophone are now being investigated.

ALLIED DEVELOPMENTS

I. <u>P. T. Crystal Evaluator</u>. In the course of our study and evaluation of $1\frac{1}{2}$-in barium titanate cylinders, a test device was developed which has shown some promise as a crystal evaluator and a polarity indicator (see Figs. 7 and 8). The device actually tests the static

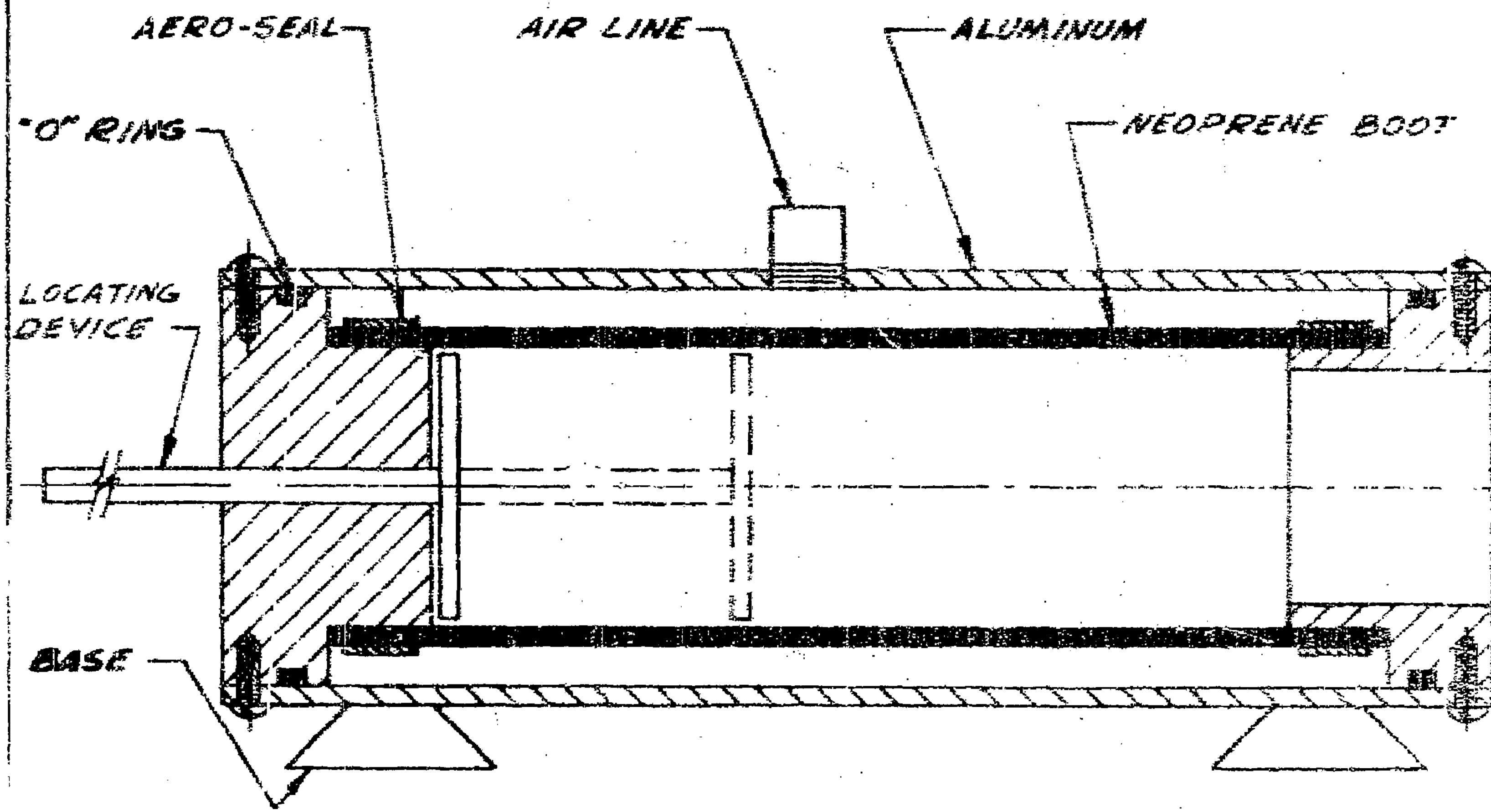


Fig. 7. P.T. CRYSTAL EVALUATOR

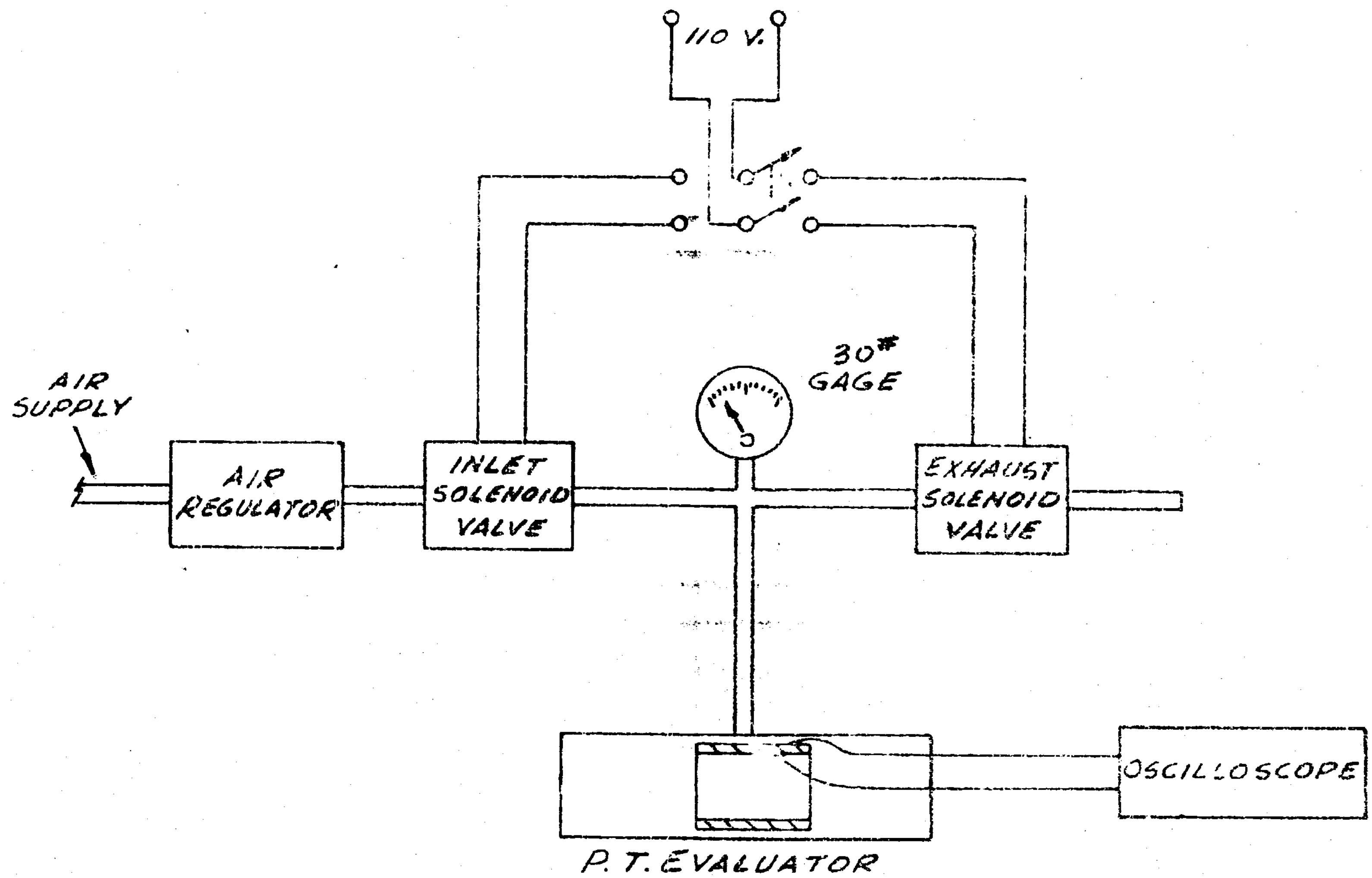


Fig. 8. FLOW DIAGRAM OF P.T. CRYSTAL EVALUATOR

voltage charge developed in a crystal by a circumferential mechanical pressure. It consists of an airtight metal unit with a cylindrical rubber boot as a liner. As air pressure is applied between the container and the rubber boot, the latter compresses the crystal which has been inserted within the boot. A known air pressure (10 psi) is applied. After a moment to allow for equilibrium, the pressure is suddenly removed and a record of voltage output of the crystal is measured on a high persistence oscilloscope. For simplicity of operation, the air supply is controlled by a pressure regulator and solenoid valves.

7 - Test Procedure. The first test operation consists of inserting the crystal into the rubber boot. Precise location of the crystal is attained by a locating rod which is withdrawn from the crystal after location. The double-pole, double-throw switch is normally positioned such that the air outlet is open and the inlet is closed. Operation of this switch applies the regulated air pressure to the crystal. Reversal of the switch opens the exhaust releasing the pressure and concurrently the electrical charge which is measured on the scope. Direction of the pulse also indicates uniformity of polarity.

8 - Possible Value. Correlation has been experimentally indicated between the voltage output of the crystal and the actual sensitivity ascertained by the calibration department. However, further development work is required before a valid relationship can be established. The mechanical force applied with this device is in the radial direction, and the electrical force is measured in this same direction (the direction of polarization) giving an indication of the response of the cylinder. This voltage output is closely related to the d_{33} quality factor proposed by crystal manufacturers. Some of the voltage measured, however, possibly is attributable to influence of output due to concurrent mechanical force in the length mode or the circumferential mode referred to as the d_{31} coefficient. For our laboratory use, nevertheless, the overall measurement is

valuable only if it can be used as a consistent standard which parallels the actual calibration results. Further investigation will be necessary to establish the usefulness of the tester. Some aberrations in the tester measurements and the calibrated sensitivity were seen in some crystals where there was a wide disparity of capacity measurement. Later development may indicate the need for applying a correction factor based on capacitive influence since the oscilloscope reading is affected by the capacitance across its input.

II. Crystal Evaluator d_{31}. Another tool for the study of crystal performance is a device permitting the application and removal of a weight to a barium titanate cylinder in the axial direction (see Fig. 9). The sudden removal of the weight causes the release of a voltage which is measured on an oscilloscope. Since the mechanical force is perpendicular to the electrical signal and the direction of polarization, the measurement should be related to the d_{31} coefficient of the piezo-electric material tested. Further work is being done with this tool in the calibration department to establish its possible value in crystal evaluation.

III. Effect of Thickened Plastic on Crystal Sensitivity. An unusual phenomenon was observed in the increased sensitivity of a barium titanate crystal that had layers of plastic applied to it, progressively increasing its diameter. As successive layers of plastic were applied, the crystal was referred for calibration. Two such samples were observed, and the results of those tests are shown in Figs. 10 and 11 on the following pages. In the case of sample X89, it was noticed that an increase in the diameter of the crystal from the original $1\frac{1}{4}$ in to $3\frac{3}{4}$ in by the application of a room-cured epoxy plastic improved the sensitivity of the crystal from 104.5 db to 102.5 db. The experiment is continuing. Little more than the actual observation of this unusual result was accomplished at the time of this writing, but it might be suggested that similar experiments might be conducted with three-element units. The effect of other types of plastic with

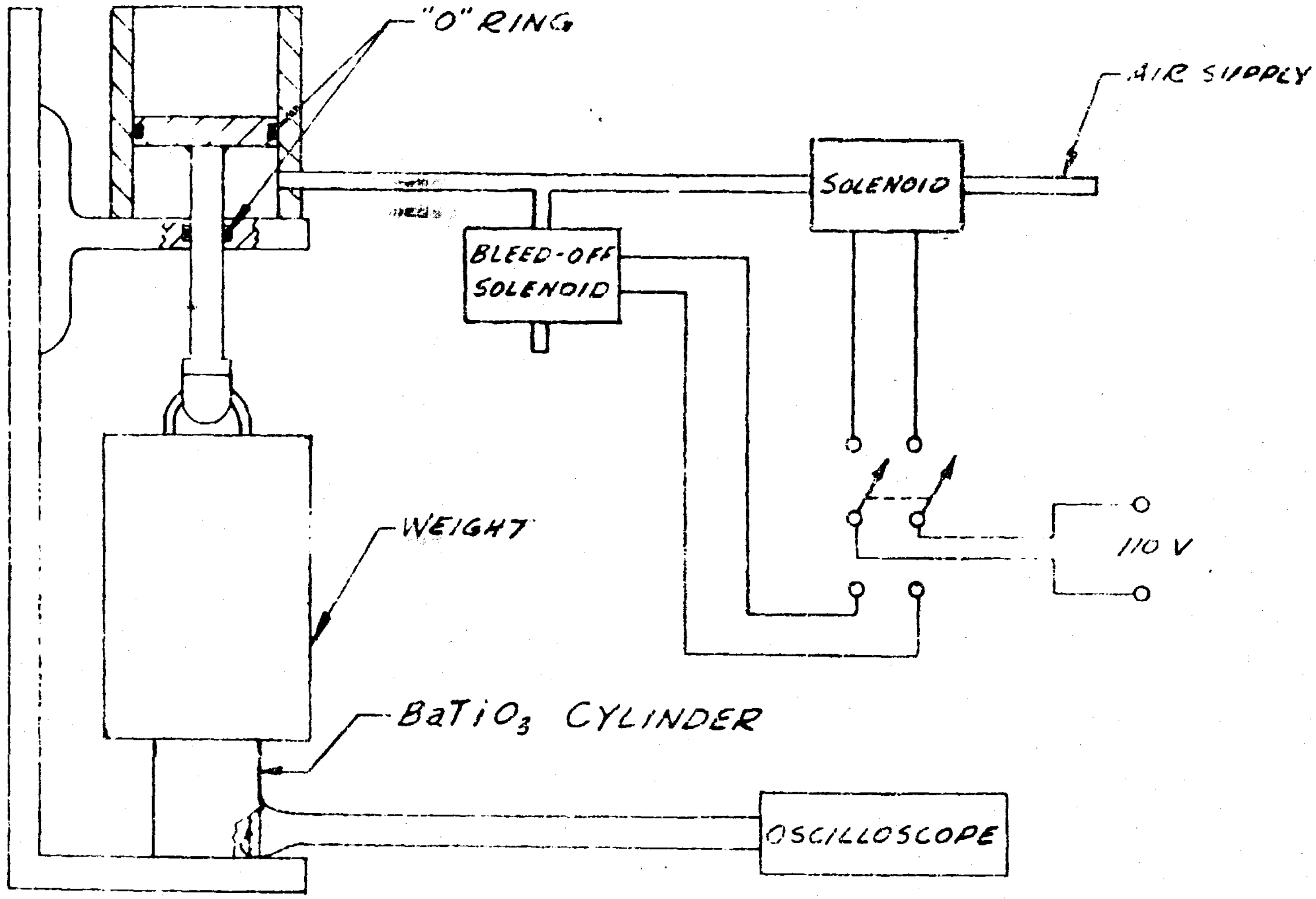
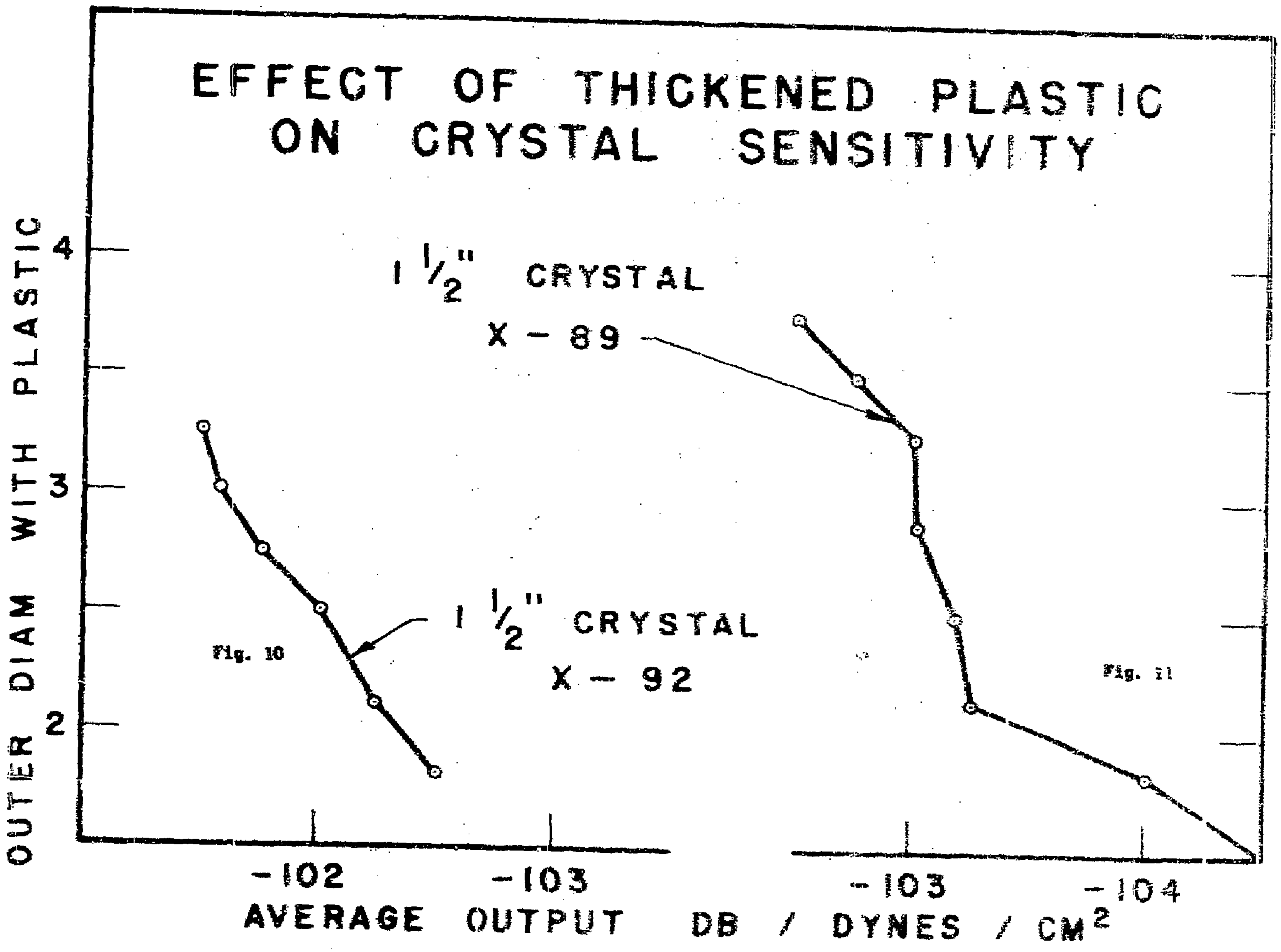


Fig. 9. CRYSTAL EVALUATOR - d_{31}


EFFECT OF THICKENED PLASTIC
ON CRYSTAL SENSITIVITY
1 1/2" CRYSTAL
X - 89
1 1/2" CRYSTAL
X - 92
Fig. 10
Fig. 11
OUTER DIAM WITH PLASTIC
4
3
2
-102
-103
-103
-104
AVERAGE OUTPUT DB / DYNES / CM²

varying densities might be pursued. Certain possible explanations for the effect have been proposed. The most plausible one is that the embedded crystal in the large surrounding plastic senses the pressure wave to which the entire surface is exposed. The plastic acts as a lever transmitting the accumulated pressure signal to the detector. More developmental work will be pursued to attempt to exploit the value this finding may have in future hydrophone construction.

CONCLUSION AND RECOMMENDATIONS

The efforts expended in the manufacture of hydrophones at Hudson Laboratories were worthwhile, aside from the financial benefit, because flexibility of hydrophone design was thereby made available to equipment designers. Variable configurations of geometry and electrical wiring were permitted without undue stress since all of the components and the techniques were at hand.

In the sound source department, too, variation of design has put into play some of the skills developed by the hydrophone group. Considerable further experimental effort should be expended in the interest of developing some of our earlier findings and improving our present materials and skills.

It has been suggested by another laboratory (Naval Air Development Center) that for an expenditure of less than ten thousand dollars, a ceramic laboratory could be set up capable of producing crystals better suited to the needs of Hudson Laboratories than those available from the inflexible industrial firms. Such a facility would also lend itself to developmental improvements in the piezo-electric materials and would permit variability of shapes and sizes. A recommendation for the setup of this facility is being published as an addendum to this report.

It is suggested that in the immediate future the matter of the improvement of sensitivity by the application of thickened plastic coverings on barium titanate crystals be further investigated. The observed increase of 2 db on a single crystal should be further investigated, and the possible utilization of the phenomenon in hydrophone design should be considered.

The use of zirconates as replacements for barium titanate elements should, because of their more acute sensitivity, be investigated more fully. Evaluation thus far has shown their merit for high pressure and low temperature use; however, obtaining them is still the major problem. At present, only one supplier is available, and for this reason prices have not been depressed by competitive influence.

Future developments in the hydrophone field will be presented periodically as addenda to this report.

ACKNOWLEDGEMENTS

These achievements were the result of the cooperative effort of Mr. Henry C. Beck, Mr. Gaetano Imperato, Mr. Thomas Kelly, Mr. Frank Kiselak, and Mr. Peter Weber of the Mechanical Engineering staff. The help of Mr. Richard McGunigle, Mr. George Seabury, and Mr. Harry Sonnemann of the Electronic Engineering staff in calibrating and testing hydrophones is also acknowledged. Of much assistance in this development program was the work of Mr. John D. Wallace and Mr. Maurice F. Pressler at the U. S. Naval Air Development Center, Johnsville, Pennsylvania.

APPENDIX

BARIUM TITANATE SUPPLIERS

Name	Type of Sample	Capacity	Sensitivity
Solar Manufacturing Co., 4553 Seville Ave. Los Angeles 58, Calif.	Single Element	.0125 mfd	-103.5 db
U S Sonics 625 McGrath Highway Somerville, Mass.	Single Elements (Special mix for low temperature use)	.0055 mfd	-102 db
Clevite Electric Components 3311 Perkins Ave., Cleveland 14, Ohio	Three Elements in Series Zirconates Sample (considered elsewhere in report)	.0160 mfd	-93.5 db
Sprague North Adams, Mass.	First Sample Single Element	.016 mfd	-103.5 db
	Three Elements Thinned Wall units	.0169 mfd	-94 db
	Unable to modify further zirconate after Jan. 1st.		
Gulton Industries 212 Durham Ave. Metuchen, N. J.	First Sample Three Element	.019 mfd.	-94 db
	Second Sample Single Element	.021 mfd	-103.5 db
Electro Ceramic (King) 2645 South 2nd West Salt Lake City 15, Utah	Single Unit	.0135 mfd	-103.5 db.
American Lava Corp. Chattanooga 5, Tenn.	Three Element	.0145 mfd	-94 db.

Aero Physics
P. O. Box 689
Santa Barbara, Calif.

Centralab Corp.
900 E. Keefe Ave.
Milwaukee, Wis.

Erie Resistor Co.
University Park, Pa.

General Electric
Electric Components Div.

Possible future sources, not now in a position to supply samples or production quantities.

Naval Air Development Center Johnsville, Pa.	Ceramic A crystals	.018 mfd	-91-92 db. Curie Point 10°C